ENERGY CONSERVATION & ECONOMIC ANALYSIS FOR PRODUCTION OF 50 000 MT/ANNUM ISOBUTYLENE PLANT USING PINCH ANALYSIS

MOHD FAIRUZ BIN MOHD JAIS

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Faculty of Chemical and Natural Resources Engineering
Universiti Malaysia Pahang

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ABSTRACT

Pinch technology is the state of the art-technique for design of energy efficient processing that allows the calculation of theoretically minimum data utilities consumption for a process based on the thermal data of process stream. The goal of Pinch analysis is to maximize the process to process heat recovery and minimize the utility requirements of heat exchanger system which offers maximum scope for energy and cost saving. The main factor that must be considered here is the determination of the stream utility used in the plant for extraction process of thermal data in the system that requires optimization. This analysis on production of 50 000 MT/Annum isobutylene plant establishes the Grand Composite Curve of the process as a function of temperature and it is important to determine the Pinch point that can be defined as the temperature where the net deficit or surplus is equal to zero. This analysis is based on thermodynamic principle that set energy savings and cost targets prior to the design of a Heat Exchanger Network with ΔT_{min}=13°C and ΔT_{min}=14°C, where the process to design and implement is complicated and critical part in order to minimizing the energy consumption and maximizing the heat and energy recovery. From this research, it can be seen that the application of heat integration using Pinch analysis method can minimize the energy usage besides lowering the production cost of 50 000 MT/A isobutylene. By using ΔT_{min}=13°C, the payback period for investment in this new heat exchanger network in this plant are 4.2 months while ΔT_{min}=14°C result in lesser payback period of 2.3 months.

ABSTRAK

Teknologi jepitan adalah merupakan satu teknik untuk menganalisa penggunaan tenaga secara efektif mengikut kaedah pengiraan secara teori daripada data utiliti yang digunakan di dalam loji untuk kesinambungan proses berdasarkan data terma proses aliran. Proses ini adalah berdasarkan prinsip termodinamik yang mensasarkan penjimatan tenaga dan penjimatan kos dalam sesebuah jaringan alat penukar haba. Justeru, tujuan utama analisa jepitan ini adalah untuk memaksimumkan proses penjimatan tenaga dan meminimumkan lagi keperluan utiliti dalam sesebuah sistem dengan menganalisa sistem alat penukar haba. Perkara permulaan yang perlu dibuat dalam proses analisa ini adalah penentuan utiliti yang digunakan di dalam alat penukar haba dan proses pengekstrakan data terma di kawasan sistem ini. Berdasarkan analisa dalam proses penghasilan 50 000 Metrik tan tahunan isobutylene, ia berkonsepkan lengkungan komposit utama yang terhasil daripada proses yang berkaitan secara langsung dengan suhu. Kewujudan lengkungan ini adalah penting untuk menentukan di mana berlakunya titik jepitan yang menjadi titik tolak permulaan proses integrasi tenaga, dan titik jepitan ini boleh didefinisikan sebagai satu nilai suhu di mana nilai defisit dan surplus adalah bersamaan sifar. Analisa ini adalah berdasarkan prinsip penjimatan tenaga yang terhasil daripada konsep termodinamik untuk merangka jaringan alat penukar haba, dan proses ini merupakan satu proses yang rumit dan perlu dibuat secara teliti supaya penjimatan yang dapat dihasilkan adalah semaksimum yang mungkin dengan menggunakan perbezaan suhu minimum bersamaan 13°C dan 14°C. Hasil daripada kajian ini didapati bahawa pengaplikasian integrasi haba ini dengan menggunakan kaedah analisa jepitan mampu untuk meminimumkan penggunaan tenaga di samping dapat menjimatkan lagi kos dalam penghasilan isobutylene ini. Keputusannya, dengan menggunakan perbezaan suhu minimum 13°C, tempoh pulangan modal untuk alat penukar haba dalam loji ini adalah selama 4.2 bulan dan 2.3 bulan diperlukan untuk tempoh pulangan modal dengan menggunakan perbezaan suhu minimum 14°C.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

CC	Composite Curve
GCC	Grand Composite Curve
GHG	Green House Green
HEN	Heat Exchanger Network
MT	Metric Tonne
SN	Sub-networking
PA	Pinch Analysis
PDM	Pinch Design Method
PFD	Process Flow Diagram
PI	Process Integration
PT	Pinch Technology
PTA	Problem Table Algorithm
STS	Shifted Temperature Scale
T-H	Temperature-Enthalpy

NOMENCLATURES

ΔH	Enthalpy Change
ΔT	Difference Temperature
ΔT_m	Mean Temperature Difference
ΔT_{lm}	Log Mean Temperature Difference
ΔT_{min}	Minimum Temperature Difference
ΔT_{in}	Difference of Temperature Interval
ΔT_{thresh}	Difference Threshold Temperature
A	Area
U	Fouling Factor
°C	Celcius
$C°_{BM}$	Bare Module Cost
C_{TM}	Total Module Cost
$F°_{BM}$	Bare Module Factor
F_m	Material Factor
F_p	Pressure Factor
K	Kelvin
CP	Heat Capacity Flow Rate
$CP_{interval}$	Interval Heat Capacity
T_{cold}	Cold Temperature
T_{hot}	Hot Temperature
T_{ci}	Inlet Temperature of Cold Fluid
T_{co}	Outlet Temperature of Cold Fluid
T_{hi}	Inlet Temperature of Hot Fluid
T_{ho}	Outlet Temperature of Hot Fluid
T_{in}	Inlet Temperature
T_{out}	Outlet Temperature
T_s	Supply Temperature
T_t	Target Temperature

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

1.1.1 Current Scenario

Isobutylene is produced commercially to used as chemical intermediate in the production of variety of products. Based on its usage, application and demand, these scenarios enhance the growth of isobutylene plant in entire world. Observed from economical perspective, the total capital investment for isobutylene plant is about RM 215 920 056.25 and the total production cost is RM 53 132 806.57. This high production and investment cost maybe reduced through an effective optimization method and technique applied to this plant. Based on data, since 1971 until 2004, energy use in petrochemical plant has increased by 206% to 33.6EJ/year and CO_2 emissions increased by 160 % to 1.0Gt/year. Petrochemicals industries has some energy relevance (accounting for approximately 10%) represent the bulk of the energy and feed stock use in this sector. Most industrial energy consumption occurs in industries that produce raw material such as chemical, petrochemicals, iron and steel, nonmetallic minerals and nonferrous metals industries. Together, these four materials groups consumed 69.9 EJ of final energy in 2004 (62% of total final industrial energy use). The chemicals and petrochemical industry alone accounts for 30% of industrial energy use (Phil Thompson C.Eng. M.I.Chem.E., UK). According to these facts, it is predicted that the world’s energy will be exhausted within a century.

In Malaysia, the government has issued many energy conservation plans for reducing the energy consumption. With the latest plan, the energy consumption is being cut down in factories and buildings, and promoting the use of renewable energy. The industrial sector, which consumes a large amount of energy, is looking for the way to use the energy efficiently in order to reduce the plant cost.

A lot of researchers in the entire world had done different studies in order to find the suitable optimization methods in the management of energy for chemical plants. Pinch technology is one of the energy optimization methods. Pinch Technology is the most practical method for applying process integration. Process Integration is a very important means of improving energy efficiency of industrial and manufacturing processes as well as minimizing their environment impact. By analyzing the thermodynamics of a process, an engineer can qualify the thermodynamic efficiency of the process, identify the regions where energy can be better utilized and define the minimum targets for energy consumption. Pinch technology is used mostly for the Heat Exchanger Network (HEN). The process pinch point refers to the energy optimum point in the process design, the temperature level above this point acts as heat sink, and the one below acts as heat source. Based on rigorous thermodynamic principles, Pinch technology matches cold streams that need to be heated with hot streams which need to be cooled, causing high degree of energy recovery. Thus pinch technology can be used to determine the minimum requirements for both hot and cold utilities in a process.

In the present energy crisis scenario all over the world, this project will optimize this isobutylene plant by applying pinch technology on 4 heat exchangers for retrofitting the heat exchanger network to obtain the best design which posses high degree of energy recovery beside reduce the cost of plant production, operating, and utilities.

1.1.2 Process Flow Diagram (PFD)

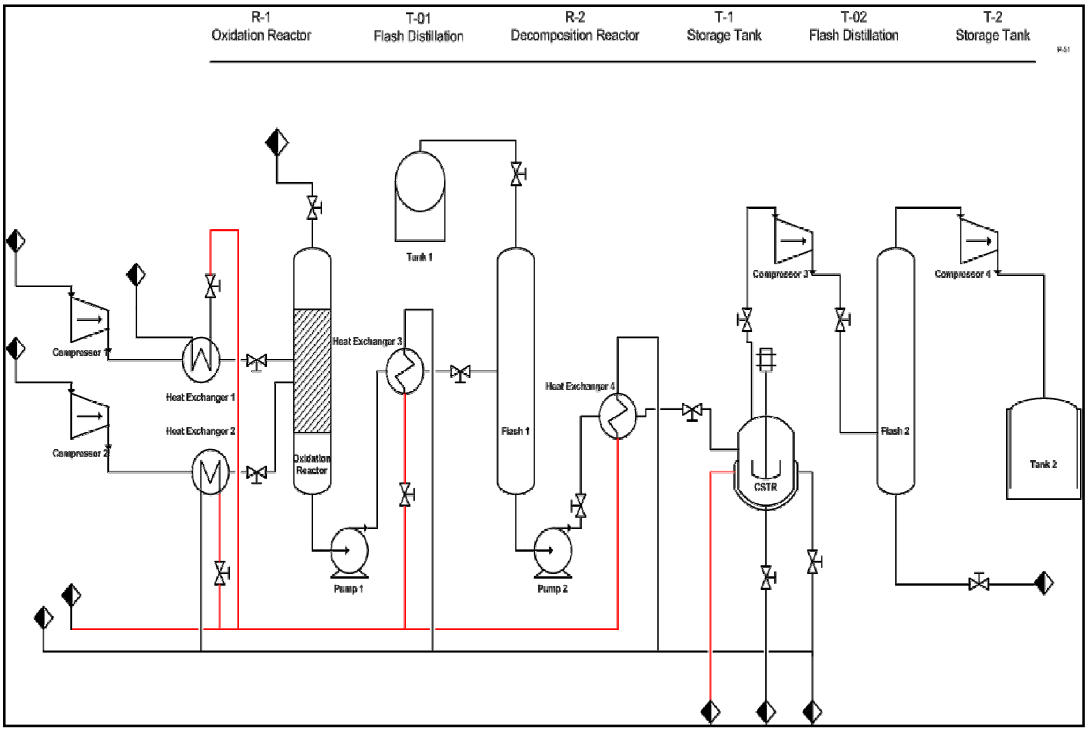

Figure 1.1 : Process Flow Diagram (PFD) of isobutylene plant

From Figure 1.1, it can be observed and summarized that the process flow diagram for this isobutylene plant consists of 4 heat exchangers where two of it are used for cooling down of the process stream and the other two heat exchangers are used for heating up.

The transfer of heat in a process fluid is an essential part of most chemical processes where heat can be transferred between two fluids. The most common type is one in which the hot and the cold fluid do not come into direct contact with each other but are separated by a tube wall or flat or curved. The transfer of heat accomplished from the hot fluid to the wall or tube surface by convection through tube wall or plate conduction and by convection to the cold fluid. It is important to determine whether the stream is cold or hot stream. Generally, hot and cold streams can be defined as:

Hot Stream : The stream that must be cooled or are available to be cooled.

Cold Stream : The stream that must be heated.

In addition, utility stream are used to heat or cool process streams, when heat exchange between process streams is not practical or economic, a number of different hot utilities (steam, hot water, flue gas, etc.) and cold utilities (cooling water, air, refrigerant, etc.) are used in this plant. The basic concept of a heat exchanger is based on the premise that the loss of heat on the high temperature side is exactly the same as the heat gained in the low temperature side after the heat and mass flows through the heat exchanger.

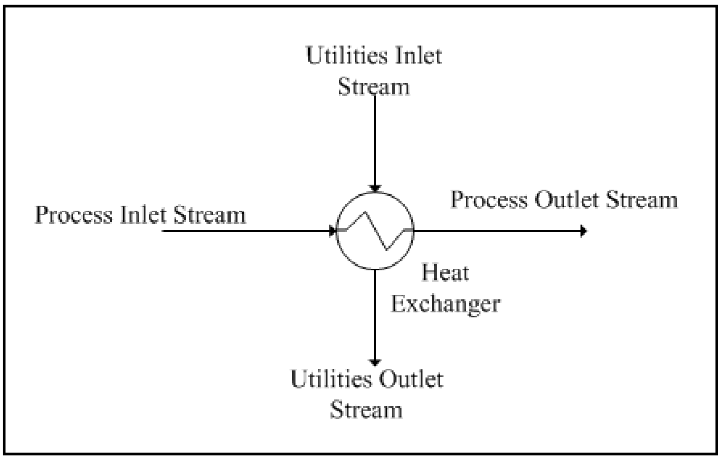

Figure 1.2 : Heat Exchanger stream flow

HEAT EXCHANGER 1

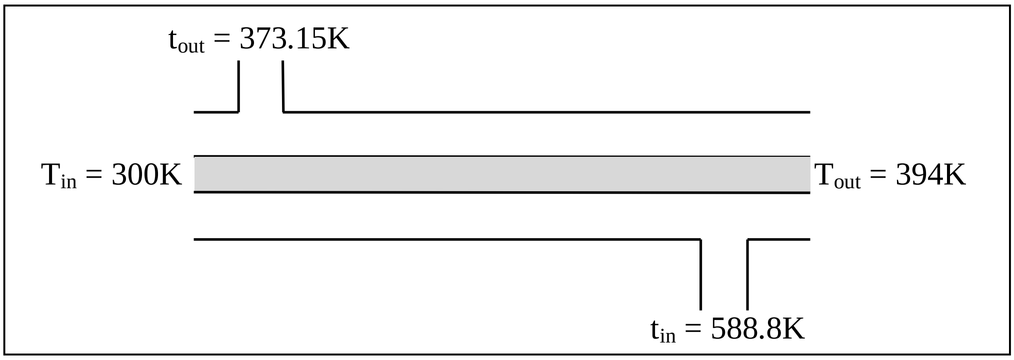

Figure 1.3 : Cross section of Heat Exchanger 1

From figure 1.3, the stream process at 300K was supplied. This stream needs to be heated to 394K to proceed for the oxidation reactor which requires higher temperature. This first Heat Exchanger was applied on that stream for this purpose. The inlet flowrate of the Heat Exchanger 1 is 5512.094 kg/hr of water steam at 588.8K. As the result, the outlet temperature of the process stream increase to 394K with decreasing t_{out} of the Heat Exchanger 1 to 373.15K.

HEAT EXCHANGER 2

Figure 1.4 : Cross section of Heat Exchanger 2

From figure 1.4, shows the initial temperature of steam process is 380K. Similar with the previous steam, it needs to be heated to 394K to proceed with the oxidation reactor which requires higher temperature for oxidation process. The second Heat Exchanger was applied on that stream with inlet flowrate of the Heat Exchanger 2 is 183.8553 kg/hr of water steam at 400K. As the result, the outlet temperature of the process stream increase to 394K with decreasing the t_{out} of the Heat Exchanger 2 to 375K.

HEAT EXCHANGER 3

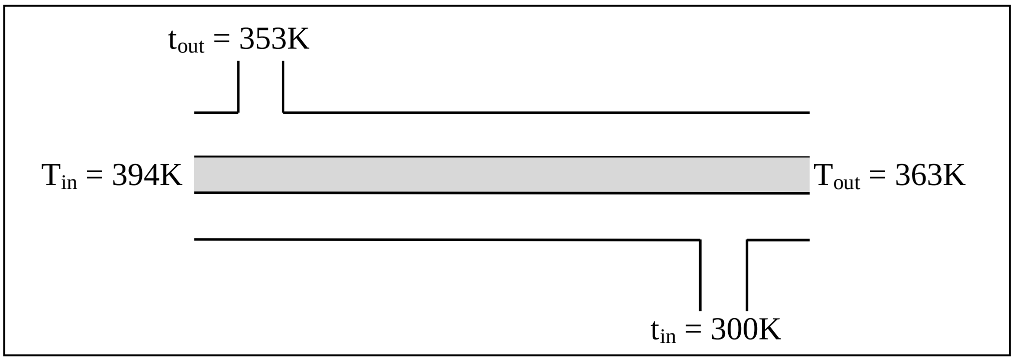

Figure 1.5 : Cross section of Heat Exchanger 3

In figure 1.5, the temperature of entering stream process is 394K. It was then lowered down to 363K before entering the flash distillation column to proceed with the separation of homogeneous mixture. The third Heat Exchanger was installed to this stream with the inlet flowrate of 88.8344 kg/hr of water steam at 300K. The outlet temperature of the process stream increase to 363K with the t_{out} of the heat exchanger 3 is 353K.

HEAT EXCHANGER 4

Figure 1.6 : Cross section of Heat Exchanger 4

Figure 1.6 simulate the purpose of Heat exchanger 4. It shows that the entering stream prior the Continuous Stirred Tank Reactor (CSTR) which require lower temperature of 363K, the forth heat exchanger was applied on that stream. The inlet flowrate of the Heat Exchanger 4 is 134.7632 kg/hr of water steam at 373K. The outlet of process stream is 363K which while for the leaving water steam, it was decreased to 358K. The overall heat exchanger used in this plant can be summarized in the following table:

Table 1.1 : Summary of Heat Exchanger

No. of Heat Exchanger	**Process Stream**		**Utility Stream**	
	T_{in} (K)	T_{out} (K)	t_{in} (K)	t_{out} (K)
Heat Exchanger 1	300	394	588.8	373.15
Heat Exchanger 2	380	394	400	375
Heat Exchanger 3	394	363	300	353
Heat Exchanger 4	373	363	373	358

1.2 Problem Statement

The importance of heat exchangers as a medium of heat transfer between specific equipments has given more good reasons for energy usage for the continuity of plant processes. The situation where most of the energy that are being used in a plant gone to waste without being recovered has led to the increasing cost of production of a plant. Basically, the energy used should not exceed the energy required in a process. The use of excessive energy will rise to environmental problems which is highly potential to increase the carbon emission to atmosphere. The increasing of carbon in atmosphere will contribute to greenhouse effect. The initial study shows that the plant process is not very efficient based on the usage of energy and high capital and production cost of the plant. The total usage energy of all heat exchangers in this plant is 3503.9039 kW which shows significantly high energy consumption thus have a potential for energy recovery analysis.

Therefore, with respect of the scenario discussed, this research is done to optimize this petrochemical plant. The main objectives is to ensure total energy used for production is being minimized and reduced without disrupting the plant process performance. To achieve this target, Pinch technology will be applied to analyze for potential energy saving. For further analysis, this research will analyze the impacts and effects of this technique towards the plant's economics.

1.3 Research Objectives

(1) To minimize the cost of utility for a chemical plant.
(2) To optimize the energy usage of the plant.
(3) To observe the effect of energy optimization to plant economy.

1.4 Scopes of the Study

(1) Performing Pinch Analysis on energy conservation in isobutylene plant using ΔT_{min}=13°C and ΔT_{min}=14°C .
(2) To obtain stream data on the process stream in the plant.
(3) Studying on heat exchangers.

1.5 Significance of the Study

(1) Optimizing the energy usage of an existing plant.
(2) Decrease quantity of the carbon emission that can contribute to the global warming.
(3) To improve the plant economy through energy saving.

CHAPTER 2

LITERATURE REVIEW

2.1 Background Research

2.1.1 History and Background

Pinch technology is a relatively modern engineering tool developed in the late 1970's and early 1980's by Phd student Bodo Linnhoff from Imperial Chemical Industries (ICI) under the supervision of Professor John Flower from the University of Leeds This new approach to evaluating the energy requirements of a site quickly identified ways of improving the overall energy use. The name “Pinch Technology” was applied because the technique identified the point or points in the energy flow where restrictions applied and hence limited one’s ability to re-use low grade energy.

The major difference between this new technology and previous engineering approaches was the formalized methodology involving the rigorous application of thermodynamic principles. Pinch technology was initially adopted by major chemical companies and the petrochemical energy (Phil Thompson C.Eng. M.I.Chem.E., UK).

Pinch analysis is a methodology for minimizing energy consumption of chemical processes by calculating thermodynamically feasible energy targets (or minimum energy consumption) and achieving them by optimizing heat recovery systems, energy supply methods and process operating conditions. It is also known as process integration, heat integration, energy integration or pinch technology.

The process data is represented as a set of energy flows, or streams, as a function of heat load (kW) against temperature (deg C). These data are combined for all the streams in the plant to give composite curves, one for all hot streams (releasing heat) and one for all cold streams (requiring heat). The point of closest approach between the hot and cold composite curves is the pinch temperature (pinch point or just pinch), and is where design is most constrained. Hence, by finding this point and starting design there, the energy targets can be achieved using heat exchangers to recover heat between hot and cold streams. In practice, during the pinch analysis, often cross-pinch exchanges of heat are found between a stream with its temperature above the pinch and one below the pinch. Removal of those exchanges by alternative matching makes the process reach its energy target.

2.1.2 Basic Pinch Analysis Concepts

The pinch analysis concept is originated to design the heat recovery network for a specified design task. The pinch analysis starts with the heat and material balances data of the process which is obtained after the core process, i.e. reaction and separation system, has been designed. Using thermal data from the process, we can set the target for energy saving prior to the design of the heat exchanger networks. The necessary thermal data is source and target temperature and heat capacity flow rate for each stream as shown in Table 2.1.

Table 2.1 : Thermal data for process streams (Linnhoff and Hindmarsh,1983)

No	Type	Temperature (T_s), °C	Temperature (T_t), °C	Flowrate (CP), kW/°C
1	Hot	150	60	2
2	Hot	90	60	8
3	Cold	20	125	2.5
4	Cold	25	100	3

Here, the hot streams are referred to the streams that required cooling, i.e. the source temperature is higher than the target. While the cold streams are referred to those required heating, i.e. the target temperature is higher than the supply. Heat capacity flow rate is defined as specific heat capacity times mass flow rate as shown below:

$$CP = Cp \times F \tag{2.1}$$

Where CP = heat capacity flow rate (kW/°C)

Cp = specific heat capacity of the stream (kJ/°C.kg)

F = mass flow rate of the stream (kg/s)

The data using here is based on the assumption that the heat capacity flow rate is constant. In practice, this assumption is valid because every streams with or without phase change can easily be described in terms of linearized temperature-enthalpy data (i.e. CP is constant). The location of pinch and the minimum utility requirement can be calculated by using the problem table algorithm (Linnhoff and Flower, 1979) for a specified minimum temperature different, ΔT_{min}. For a ΔT_{min} of 20 °C, the results from this method are shown in Table 2.2:

Table 2.2 : The problem table for data given in Table 2.1 (Linnhoff and Hindmarsh, 1983)

Subnetwork	**Streams & Temperatures**				**Heat Deficit**	**Accumulated**		**Heat Flows**	
	Cold Stream	**T (°C)**		**Hot Stream**		**Input**	**Output**	**Input**	**Output**
	(3) (4)		150	(2)					
SN1		125	145		-10	0	10	107.5	117.5
SN2		100	120		12.5	10	-2.5	117.5	105
SN3		70	90		105	-2.5	107.5	105	0
SN4		40	60		135	-107.5	27.5	0	135
SN5		25			82.5	27.5	-55	135	52.5
SN6		20			12.5	-55	-67.5	52.5	40

In the table the stream data are shown on the left. The network is divided into six sub-networks (SN1-SN6) corresponding to the temperature interval. The interval is defined by process stream supply and target temperatures. For example, SN2 is defined by the target temperature of stream No.3 and No. 4. The important feature of this method is the separation between hot and cold streams by ΔT_{min}. This feature ensures the feasibility of complete heat exchange between the hot and cold streams.

In other words, for each sub-network there will be either a net heat deficit or surplus as shown in Heat Deficit column (column 1) in Table 2.2. The sign convention for heat deficit is positive while the negative is used for heat surplus.

Another important feature of the problem table algorithm is the heat cascade, i.e. heat is transferred from the high to low temperature sub-networks. This idea is used in calculation of accumulated heat as shown in column 2 and 3 of Table 2.2. Initially, it is assumed that no heat supply from external utilities. The output for each sub-network is obtained by adding the surplus to the input of that sub-network. The output is then used as an input for the next sub-networks. The procedure is repeated until all of the network heat flows are calculated as shown in equation

$$\text{Heat flow input} = \text{Heat flow output} + \text{Heat deficit} \qquad (2.2)$$

To be feasible, the flow of heat from sub-network to sub-network must not be negative. Therefore, the heat has to be added into a network to ensure that the heat flows are non-negative. The minimum utility usage is observed when heat flows in the network are zero. The input to the hottest interval for this case is the minimum hot utility requirement for the network, while the cold utility usage is the output from the coldest sub-network. The results of the problem table algorithm can be shown diagrammatically called “Transshipment heat flow diagram” as shown in Figure 2.1(a). All heat flows are calculated by problem table algorithm. It can be seen from this diagram, the heat flow from SN3 to SN4 is zero while other flows are positive. The point where value of the heat flow is zero represents the pinch point.

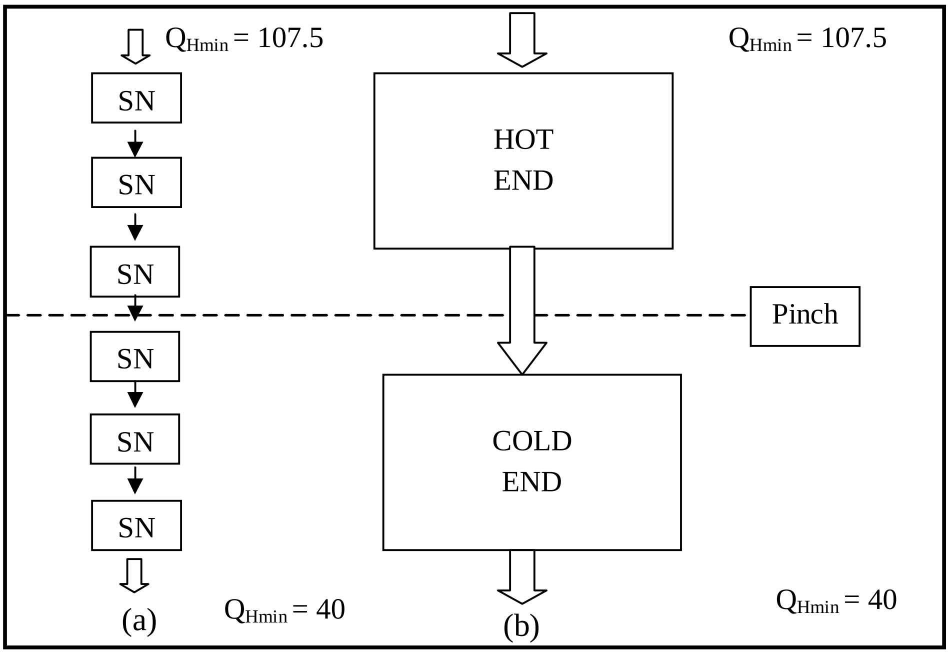

Figure 2.1 : (a) Transshipment heat flow diagram for data in table 2.1
(b) Sub-networks combined into a hot and cold region
(Linnhoff and Hindmarsh, 1983).

The significance of the pinch is shown in Figure 2.1(b). The pinch separates the problem into two thermodynamic regions, namely, hot end and cold end. The hot end is the region comprising all streams or parts of streams above the pinch temperature. Only hot utility is required in this region but not cold utility. The cold end is the region comprising all streams or parts of streams below the pinch temperature. Cold utility is required in this region but not for hot utility. There is no heat transferring across the pinch, therefore, the utility requirement is the minimum. As described previously, the hot end requires only hot utility so it acts as a heat sink while the cold end requires only cold utility so it acts as a heat source. To achieve this minimum requirement, the design has to obey the pinch principle. The pinch principle comprises of :

(1) There must not be heat across the pinch.
(2) There must not be external utility cooling above the pinch.
(3) There must not be external utility heating below the pinch.